AD NUMBER
AD807662
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 20 JAN 1967. Other requests shall be referred to Air Force Test Applications Test Center, Washington, DC.**
AUTHORITY
AFTAC ltr 25 Jan 1972

TR67-2

807662

TECHNICAL REPORT NO. 67-2

MUTICOMPONENT STRAIN SEISMOGRAPH
Quarterly Report No.6, Project VT/5081
1 October to 31 December 1966

TELEDYNE INDUSTRIES
GEOTECH DIVISION
GARLAND TEXAS

BEST
AVAILABLE COPY

TECHNICAL REPORT NO. 67-2

MULTICOMPONENT STRAIN SEISMOGRAPH
Quarterly Report No. 6, Project VT/5081
1 October to 31 December 1966

Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

Acknowledgement

This research was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, and was monitored by the Air Force Technical Applications Center under Contract No. AF 33(657)-15288.

TELEDYNE INDUSTRIES
GEOTECH DIVISION
3401 Shiloh Road
Garland, Texas

20 January 1967

<u>IDENTIFICATION</u>

AFTAC Project No.	VELA T/5081
Project Title:	Multicomponent Strain Seismograph
ARPA Order No.	624
ARPA Code No.	8100
Contractor:	The Geotechnical Corporation Garland, Texas
Date of Contract:	1 July 1965
Amount of Contract:	$290,951
Contract No.	AF 33(657)-15288
Contract Expiration Date:	31 December 1966
Project Manager	R. C. Shopland, BR 8-8102

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS, Continued

ABSTRACT

Phase responses of the strain seismographs indicate appreciable deviations from theory. However, good cancellation of Rayleigh waves with combinations of strain and inertial seismographs indicates acceptable phase match. Unpredicted phase discrepancies of approximately 5 degrees in the 0.8 cps galvanometers of the strain seismographs can be eliminated by a simple conversion to a 3 cps system. Uncertainties in the phase response of the calibrators on the strain seismometers can be resolved by installing a monitor at the calibrator.

The main effort on the program has been shifted toward evaluating the directional capabilities of the strain-inertial combinations in the long-period spectrum. A combination of long-period strain and inertial seismographs with matched frequency responses has been designed and is being put into operation at WMSO. The technique of detecting long-period (15-20 sec) surface waves masked either by microseisms or by surface waves from another event is demonstrated using 6 sec surface waves from the short-period strain directional array.

To minimize off-line summing of data from individual seismographs of the eight-component short-period strain directional array, the data will be summed on-line and recorded on a Develocorder at WMSO. This system will be an operational prototype of a strain system capable of enhancing short-period signals. The transition to on-line operation is nearly complete.

A comparison of the plastic-cased borehole and the steel-cased borehole indicates that the latter is not responding properly to earth strain.

Theoretical expressions for displacement and differential displacement due to incident SV waves have been derived. Relative values of displacement and differential displacement have been computed and are compared to a recording by the strain and inertial seismographs at WMSO.

MULTICOMPONENT STRAIN SEISMOGRAPH

1. INTRODUCTION

This report discusses technical findings and accomplishments in a program of strain seismology under Contract AF 33(657)-15288 in the period 1 October to 31 December 1966. The work reported herein covers development of a system of 3-component strain and 3-component short-period inertial seismographs having matched amplitude and phase responses in the frequency range 0.01-10 cps.

This report is submitted in compliance with Item 6 of Exhibit A, Statement of Work to be Done, AFTAC Project Authorization No. VELA T/5081. The report is presented in the same sequence as the tasks in the Statement of Work. The Statement of Work is included as an appendix.

2. INSTRUMENTATION DEVELOPMENT

2.1 PHASE ERRORS IN THE STRAIN SEISMOGRAPHS

Phase responses run on the strain seismograph system deviate from the theoretical system response. On the horizontal strain seismographs, for example, deviations average 9° lag at 0.6 cps, 10° lag at 1.0 cps, and 31° lag at 4.0 cps.

Investigation of this problem has shown that most phase readings in the various components of the systems lag the theoretical response. Therefore, the additive effect becomes serious, especially at higher frequencies. Phase errors have been located in the phototube amplifiers and the strain seismometers.

2.1.1 Phototube Amplifier Phase Error

The phototube amplifiers exhibit two types of phase errors. The first error involves an apparent change in the galvanometer free period as installed in the system and properly damped. Recent checks of all strain PTA's show that the damped "free" period (point of 90° phase lag) occurs at approximately 0.76 cps instead of 0.8 cps on four of the instruments. An error such as this will cause the phase curve to shift with frequency, producing lagging phase errors of approximately 5° at frequencies in the band of interest.

The second type of error in the PTA's causes the phase curve to rotate, producing increasing phase lag with frequency. Figure 1 shows two phase responses of the strain north amplifier system compared with the theoretical response. The first was produced by driving the galvanometer to produce a PTA output of 0.5 V p-p at 0.3 cps and the second to produce an output of 5.0 V p-p at 0.3 cps. Although the cause of this error has not been determined, the effect is an apparent decrease in galvanometer damping with increasing driving voltage at frequencies below 3 cps. It should be noted that errors such as this will be greater at high calibration signal levels and less at low seismic signal levels.

2.1.2 Strain Seismometer Response

Phase response tests of the strain seismometers indicate increasing phase lag with frequency. In the horizontal case, these errors are approximately 5° from 0.1 to 2.0 cps, increasing to about 15° at 6 cps. The vertical seismometers exhibit phase errors approximately double those on the horizontal instruments. Tests of the magnetostrictive calibrator on the vertical seismometer, which were discussed in Technical Report 66-93, indicate that at least part of the phase error in the seismometer is produced by the calibrator. It is possible that the electromagnetic calibrators on the horizontal instruments produce similar errors. In order to determine whether these errors are produced in the calibrators or in the seismometers, it is ncesssary to mount a displacement transducer near the calibrators of both seismometers. Such a monitor is feasible and can be built at reasonable cost.

2.1.3 Conclusions

Additive lagging phase errors from the above causes adequately explain those errors noted during seismometer calibration. It is also apparent that a significant part of the error noted during calibration is not present in the seismograph outputs under operational conditions. The fact that combinations of strain and inertial seismographs have produced good cancellation of Rayleigh waves indicates that calibrations are not true representations of seismograph operation.

2.2 STRAIN SEISMOGRAPH IMPROVEMENTS

A significant improvement in matching strain and inertial seismographs can be realized by operating both systems with identical galvanometers and inserting a filter in the strain system to match the inertial seismometer response. Such a filter has been built and tested with excellent results. Figure 2 shows a block diagram of the proposed amplifier system with amplitude and phase

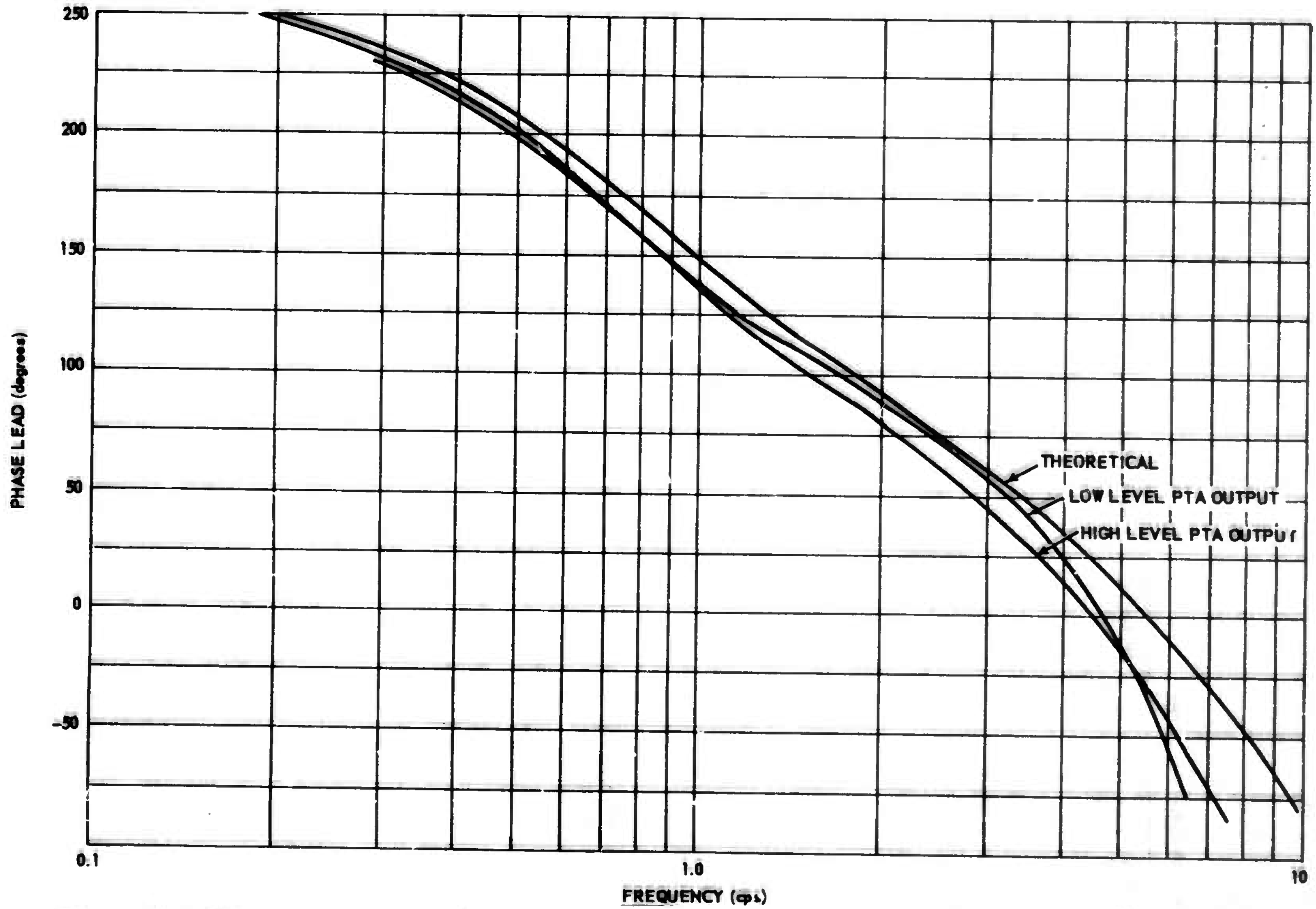


Figure 1. Phase responses of strain north system without transducer plus 180° showing apparent decrease in galvanometer damping with increasing driving voltage. The theoretical curve is included for comparison. Note also phase errors caused by galvanometer free period being less than 0.8 cps

G 2127

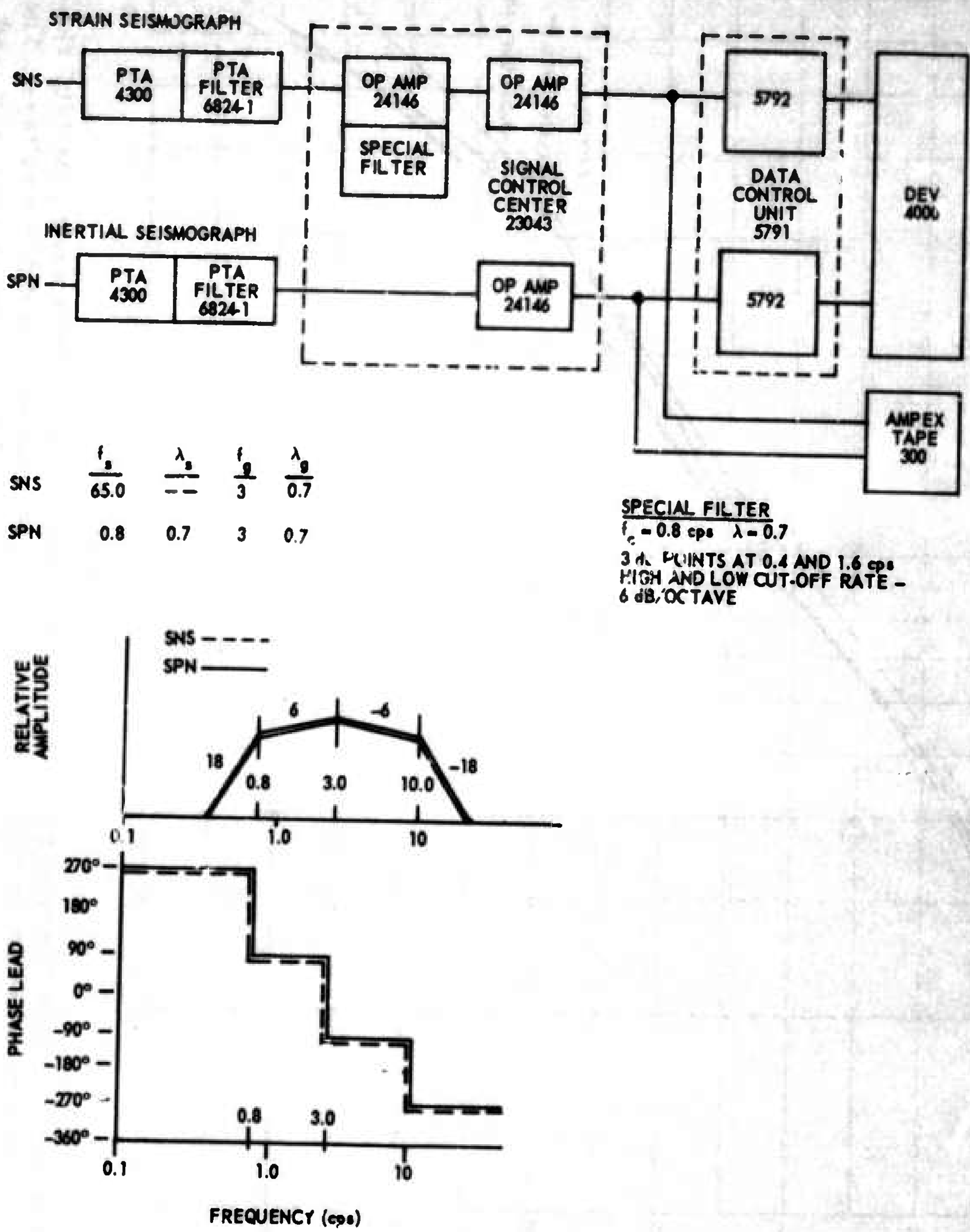


Figure 2. Block diagram of strain and inertial seismograph with matched amplitude and phase responses obtained with 3 cps galvanometers and a special matching filter

G 2128

response asymptotes. Figure 3 shows the phase response of a PTA and special filter combination. Minor deviations from the theoretical response occurring above 4.0 cps are due to phase errors in the PTA electronics.

Use of this system would eliminate phase errors discussed in paragraph 2.1.1 above, improve overall system stability, and reduce maintenance. Modification of the present system can be accomplished with a minimum of data loss and at low cost.

3. SEISMOGRAPH DEVELOPMENT

3.1 SEISMOGRAPH PHASE STABILITY

In mid-October, components of the strain and inertial seismograph systems were adjusted to produce phase responses which matched theoretical values as closely as possible. In order to eliminate uncertainties in the response of the strain seismometers and/or their calibrators, response measurements for the strain system were obtained by inserting a signal into the amplifier systems. On 13 October, a 16-point phase response was obtained for all instruments and weekly 5-point checks continued throughout the period.

Data from these phase responses were tabulated and standard deviations for each instrument were determined at 1.0 and 4.0 cps. The pendulum seismographs were found to be very stable, with deviations averaging 1.6° and 1.7° at 1.0 and 4.0 cps, respectively. The strain instruments without their transducers exhibited deviations averaging 3.3° and 6.3° at 1.0 and 4.0 cps, respectively. The phase responses of both systems showed little deviation at frequencies below 1.0 cps.

Although the strain amplifiers exhibit some phase instability which could be improved by incorporating modifications discussed in paragraph 2.2 above, all instruments can be considered sufficiently stable for operation of matched systems.

3.2 LONG-PERIOD STRAIN

Late during this reporting period, it was decided to place the main effort on evaluating the directional capability of the strain array in the long-period spectrum. To avoid the time-consuming setup of long-period inertial seismometers, data from WMSO long-period instruments will be used and the response of a strain seismograph will be matched to that of an inertial seismograph. Initially, the long-period east inertial and long-period east

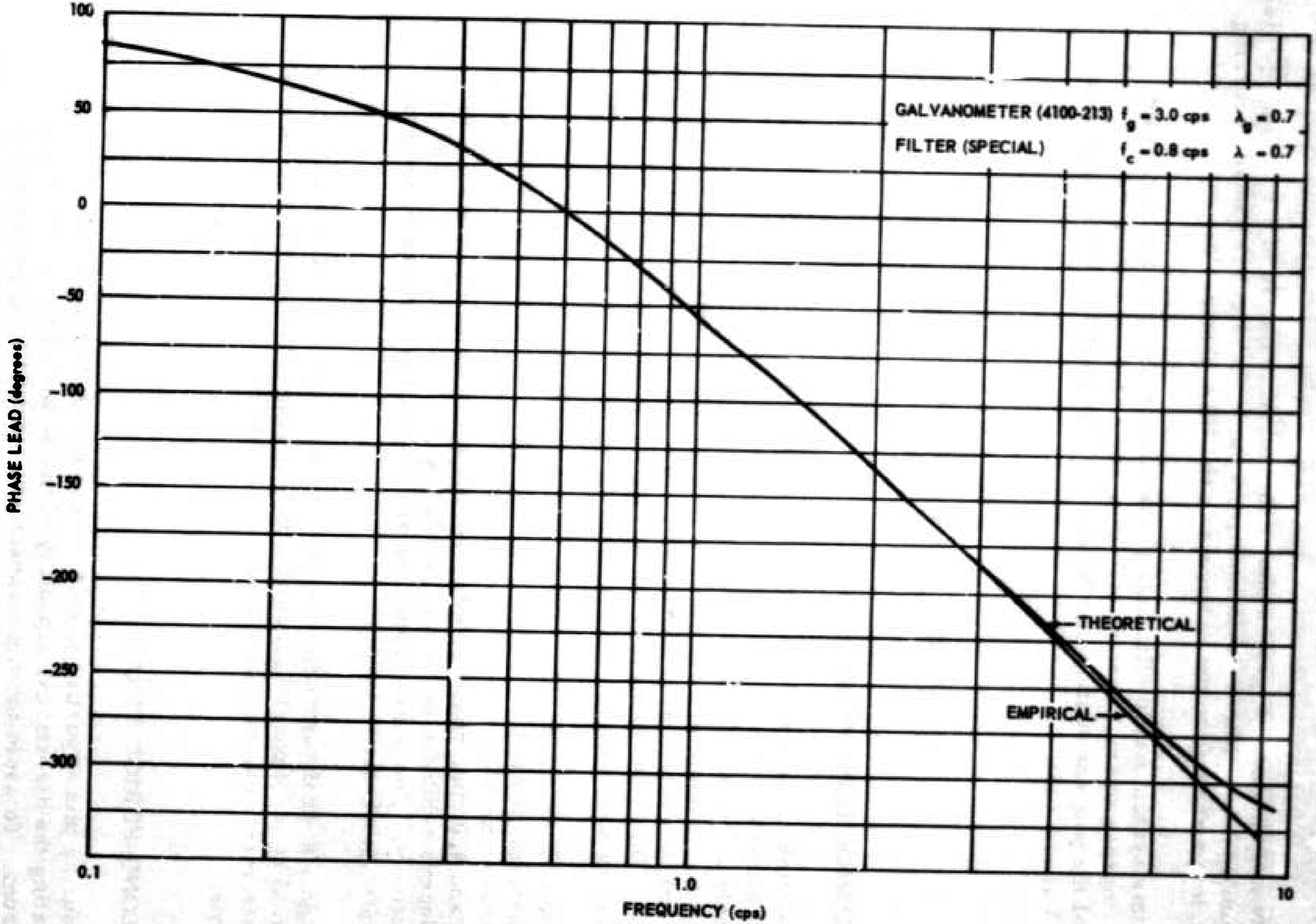


Figure 3. Phase response of phototube amplifier with 3.0 cps galvanometer followed by special filter to match inertial seismometer

G 2129

strain channels will be recorded, with the strain seismometer operating into a long-period (110 sec) galvanometer followed by a special filter. This special filter has been built and is now being tested in the laboratory. All other equipment is available. The amplitude response asymptotes for the long-period strain and inertial system and their components are shown in figure 4.

3.3 HORIZONTAL STRAIN SEISMOMETER HOUSING MODIFICATION

Further modifications to the horizontal strain seismometer housing which were previously planned were begun on 5 December 1966. These modifications included extending the tank vaults on the fixed ends of the strain standards and installing steel covers in the culverts leading to the surface at a depth of 0.5 m below the surface. The tank vault extensions were designed to provide both easier maintenance and improved sealing. The culvert covers were necessary to minimize wind noise on the seismometers and for personal safety. The modifications were completed with a minimum of data loss.

3.4 MAINTENANCE

3.4.1 Vertical Strain Seismometers

The vertical strain seismometer installed in the borehole with compliant casing was put into operation on 4 October. It was found that losses in this seismometer which were reported in Technical Report 66-93 were caused by friction in the transducer clamp assembly. Special installation techniques were developed for installation of this seismometer and the problem will be investigated after evaluation tests of the new borehole are completed. Operation of both verticals has continued throughout this period without maintenance.

3.4.2 Horizontal Strain Seismometers

Maintenance was performed on the quartz tube standards of north and northwest strain seismometers during October and November, respectively. In both cases, the tube was found to be broken near the electromagnetic calibrator. It is possible that the epoxy used to mount the calibrator coils may have contributed to the breakage due to unequal expansion and contraction with changing temperature or humidity. This problem is being investigated and the use of particular epoxy compounds will be avoided in the future. It may be necessary to redesign the calibrator to fully eliminate this problem.

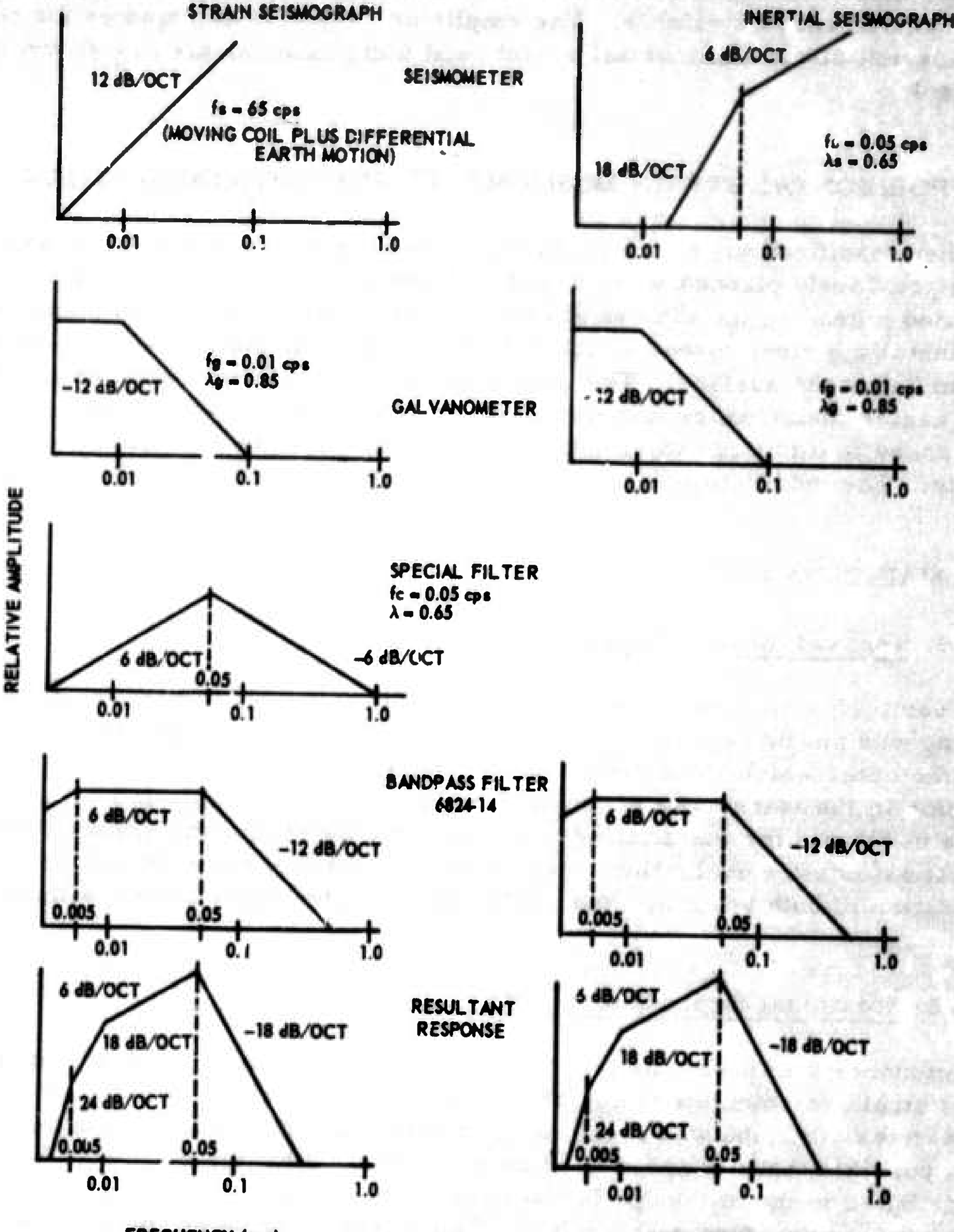


Figure 4. Asymptotic amplitude responses of long-period strain and inertial seismographs and their components

G 2130

4. EVALUATION

4.1 EVALUATION OF IMPROVED HORIZONTAL STRAIN HOUSING

Microseisms recorded during periods when the wind was blowing between 0-5 mph, 10-15 mph, and 25-30 mph have been selected to evaluate the improved horizontal strain housing at WMSO. Samples recorded by the north and east strain seismographs prior to and following the improvements have been digitized and spectra of the samples have been obtained. A computer program is currently being written that will employ the magnitudes of the spectra to evaluate the reduction of the horizontal strain seismometers' sensitivity to wind noise.

5. APPLICATIONS

5.1 DATA COLLECTION

5.1.1 Routine Recording

A short-period system consisting of 6-strain and 5-inertial seismographs has been operating to collect data to be used in determining the usefulness of strain signals for signal-to-noise improvement and for wave identification.

5.1.2 Directional Array On-Line Recording

To minimize off-line processing of the eight-component short-period strain directional array, the array will be recorded on-line at WMSO beginning in the latter part of January 1967. An AEI analog computer, TR-10, has been obtained from Contract US 33(657)-7060 for use in the on-line recording process. WMSO Develocorder No. 4 has been obtained on a temporary basis to record the array data.

5.2 COMPARISON OF THE 2 VERTICAL STRAIN SEISMOGRAPHS AND THE 2 SETS OF ORTHOGONAL HORIZONTAL STRAIN SEISMOGRAPHS

In Monthly Report No. 12, Project VT/5081, results from comparison of the two sets of orthogonal horizontal strain seismographs were given. The results showed a high degree of similarity.

Theory predicts that any set of orthogonal horizontal strain seismometers and vertical strain seismometers will have an omnidirectional response and will have similar outputs. Therefore, the two vertical strain seismometers were compared with one set of orthogonal horizontal strain seismometers to verify proper operation.

Three seismic noise samples were randomly selected from data recorded over a period of 5 days. The summation of the northeast and northwest horizontal strain seismograph (Σ SNE, SNW) outputs was used as a control signal to compare the two vertical strain seismograph outputs. The analog output of Σ SNE, SNW was subtracted from each vertical strain analog output giving an analog difference. A 50-second sample from each of the three seismic noise samples processed was analyzed using the Geotech Analog Spectral Analyzer.

The spectrograms revealed two important facts about the two vertical strain seismographs. First, the data recorded by the vertical strain seismograph from the old steel cased borehole (SZ_1) at a depth of 18 meters to 36 meters displayed poor similarity with data from both the vertical strain seismometer in the new plastic cased borehole (SZ_2) and the orthogonal horizontal strain seismometers. This is illustrated in figure 5 where the spectrogram for the analog difference between the SZ_1 data and ΣSNE, SNW data exhibits several high spectral peaks in the region of 0. 1 cps to 0. 4 cps which do not appear on the SZ_2 spectrogram for the same time interval. This dissimilarity of SZ_1 with the orthogonal horizontal strain seismographs has been observed in the past and introduced questions about possible problems existing within either the seismometer or the borehole. To resolve these questions, a second borehole with a plastic casing between 18 meters and 36 meters depth was drilled. The data from the new borehole exhibit a higher degree of similarity with ΣSNE, SNW than does SZ_1 except for two spectral peaks about 0. 4 cps and 0. 75 cps. After the vertical strain seismometer was installed in the new borehole, a nonseismic noise was observed. This noise would vary in amplitude during a 24-hour period, sometimes disappearing into the seismic background noise. The predominate frequencies of the noise were approximately 0. 4 cps and 0. 7 cps. A sample of the nonseismic noise on SZ_2 is shown in figure 6. As the months passed, the maximum amplitude of the noise became less and disappeared into the seismic background noise. However, when the Σ SNE, SNW output was subtracted from the SZ_2 output, the nonseismic noise again became visible. Spectrograms of the residual signal from the comparison were made and the spectral peaks are quite evident in all three samples processed. In figure 7 are spectrograms of the three samples displaying spectral peaks about 0. 4 cps and 0. 75 cps. The source of this nonseismic noise is believed to be the borehole. There are two reasons supporting this conclusion. First, two identical vertical strain seismometers were installed in the new borehole at different times and both recorded the nonseismic noise. Secondly, as time passes, the maximum amplitude of the noise becomes smaller. Since the level of the noise is decreasing with time, the borehole is apparently settling and will reach an equilibrium. Later data will be analyzed to verify the above conclusions.

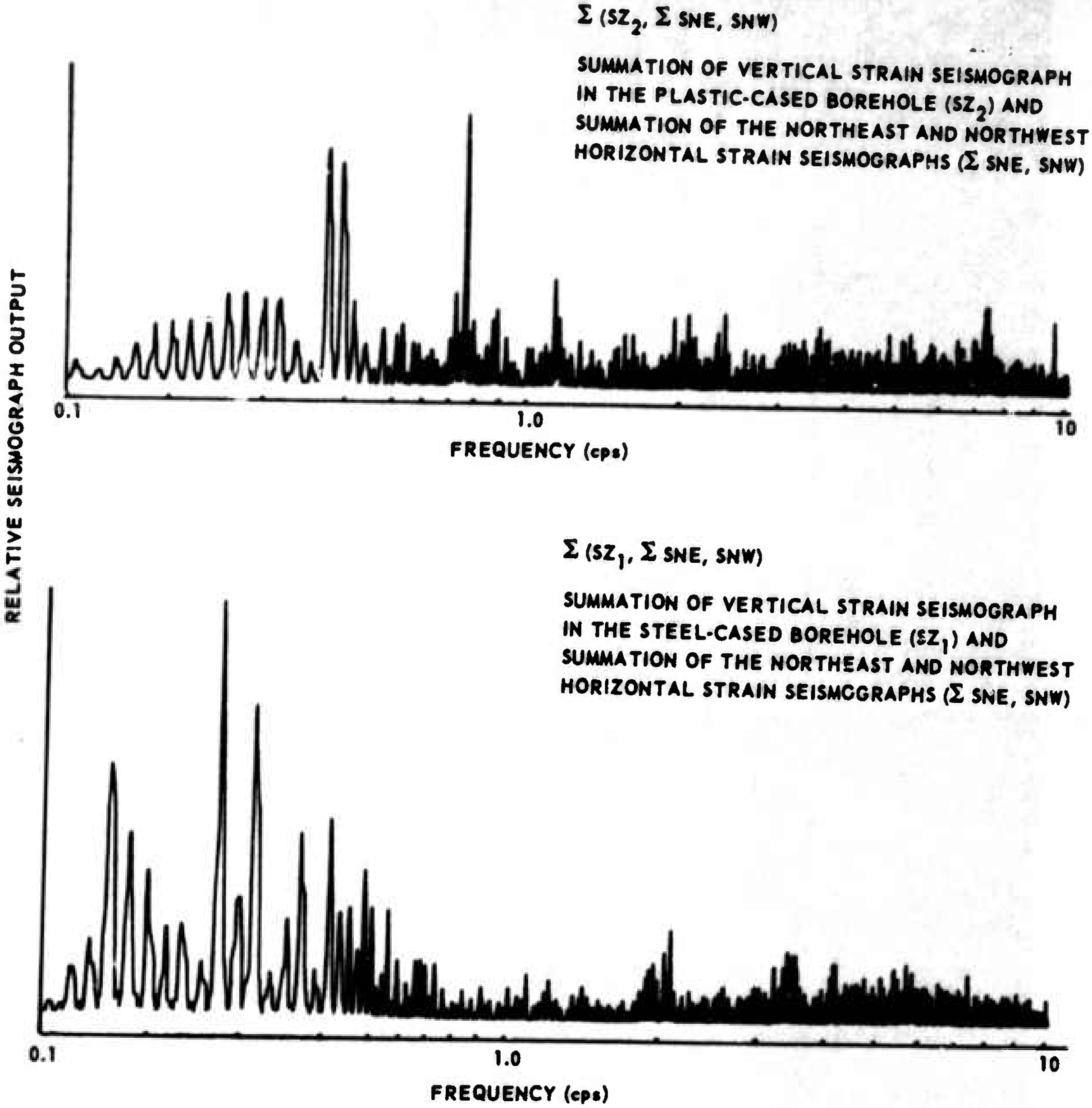
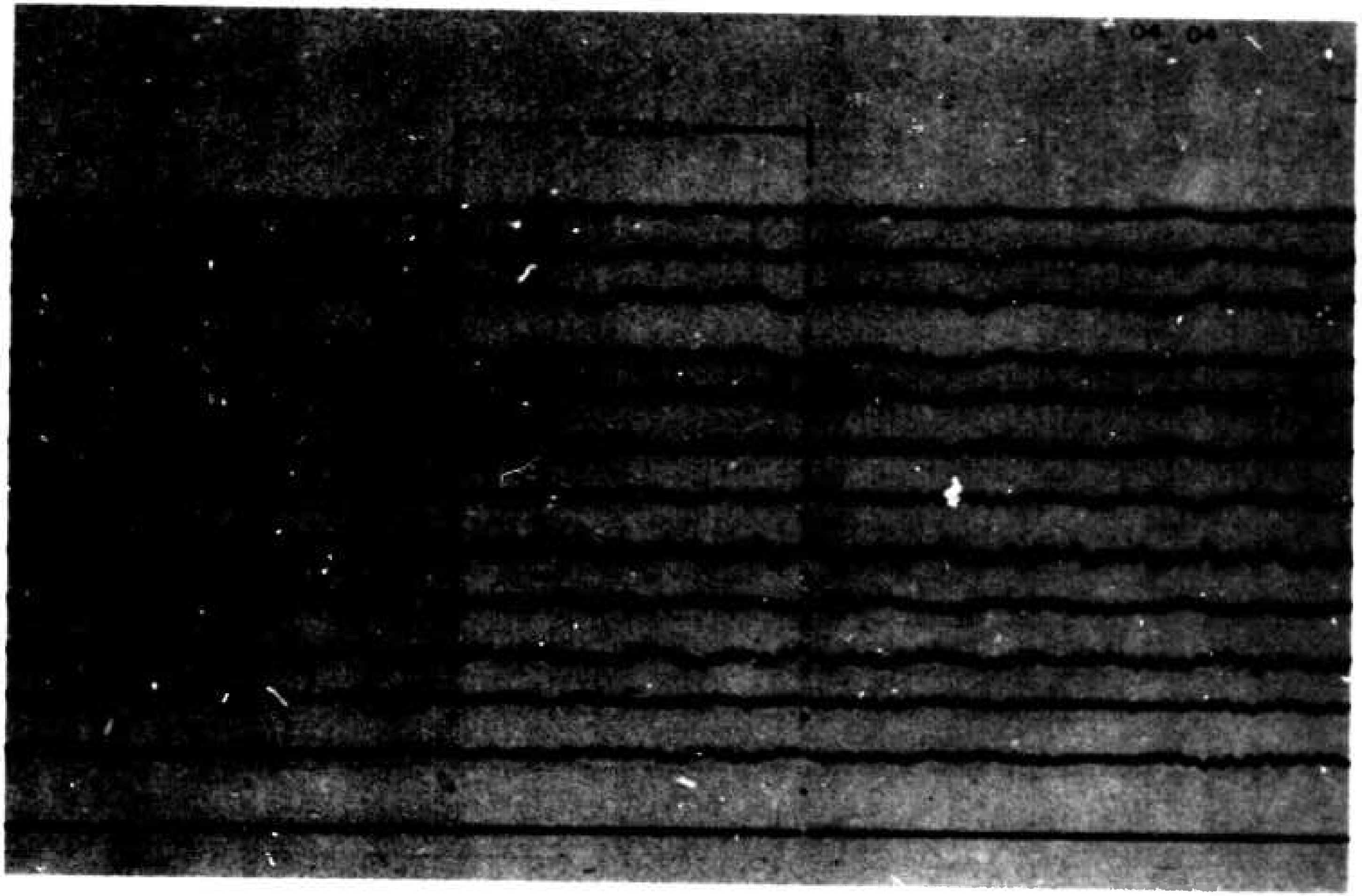


Figure 5. Spectrograms of the summations, $\Sigma(SZ_2$, Σ SNE, SNW) and $\Sigma(SZ_1$, Σ SNE, SNW), showing the dissimilarity of the outputs of the two vertical strain seismographs (SZ_2 and SZ_1). The spectrograms are of recordings made simultaneously

G 2131

SZ_2



WMSO
4 AUG 1966
RECORD NO. 216

Figure 6. Seismogram showing a sample of the nonseismic noise recorded by the vertical strain seismograph from the plastic-cased borehole (SZ_2)

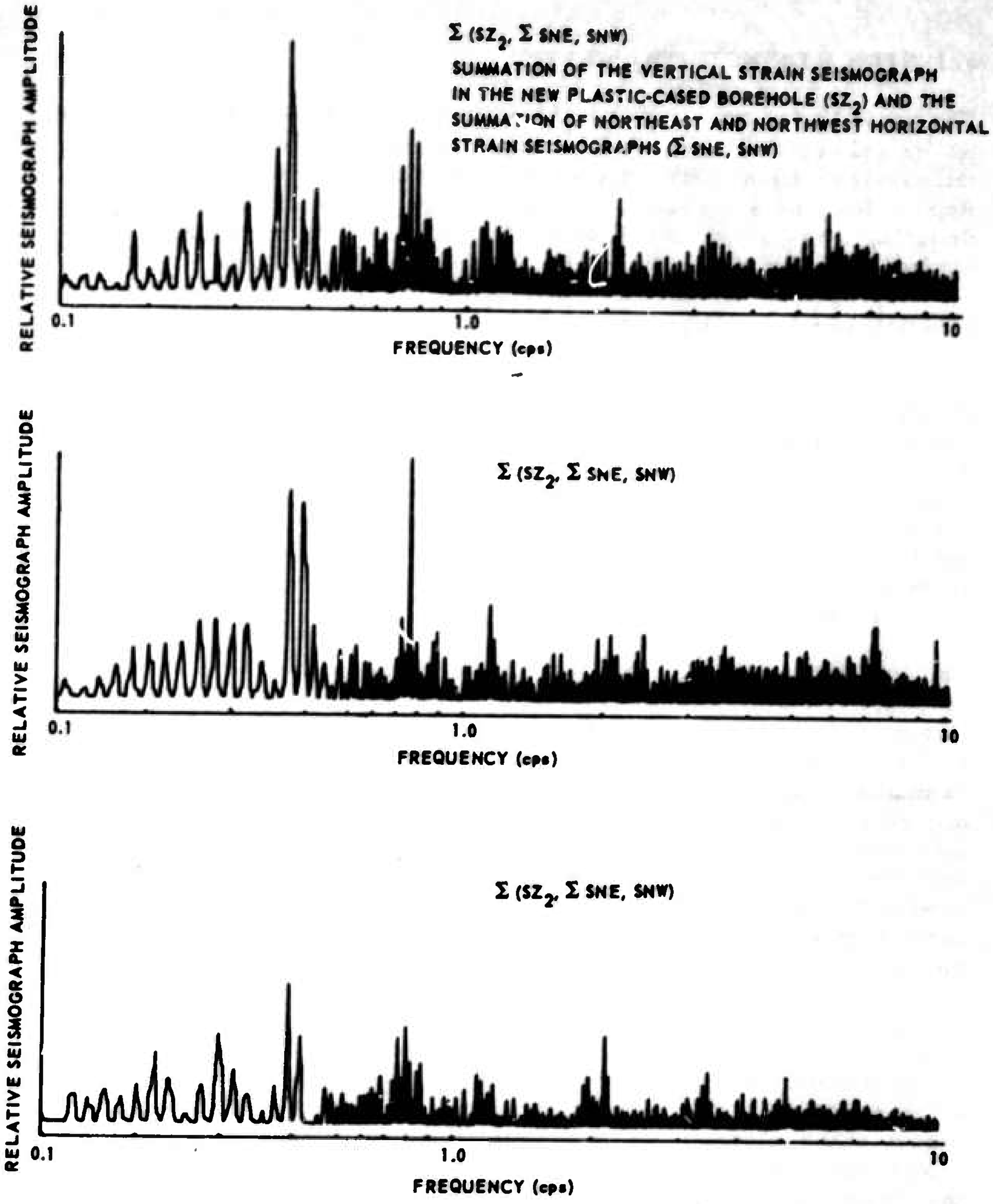


Figure 7. Spectrograms of the summations $\Sigma(SZ_2, \Sigma SNE, SNW)$ for three 50-second seismic background noise samples recorded on 9, 10, and 13 October 1966 showing spectral peaks about 0.4 cps and 0.75 cps made by a nonseismic noise generated in the new plastic-cased borehole at WMSO

G 2132

5.3 STRAIN DIRECTIONAL ARRAY

The capability of the short-period strain directional array to enhance body waves and surface waves from earthquakes and explosions by rejecting microseisms from various directions has been illustrated in Technical Reports Nos. 66-5 and 66-45. Our main effort is now being directed toward detecting long-period surface waves masked either by microseisms or by surface waves from another event. Since data from matched long-period seismographs are not available in a form that can be processed, short-period data will be used to illustrate the technique.

To simulate a simultaneous arrival of surface waves from two sources, magnetic tape data recorded on different dates were summed to form a composite record. The composite consisted of a teleseismic event having 5- to 6-second surface waves and a microseismic storm consisting of 5- to 6-second surface waves. The event was from the Revilla Gigedo Island region (azimuth = 211°, Δ = 17.5°) and was recorded by both the east strain and inertial seismographs on 4 August 1966. The microseismic storm waves in the composite were taken from data recorded on 4 February 1966 by both the east strain and inertial seismographs.

The strain directional array results from the difference between the azimuthal response of the horizontal strain and inertial seismometers. The horizontal strain seismometer has a $\cos^2 \alpha$ azimuthal response resulting in like signs at zero and 180 degrees. The inertial seismometer, however, has a $\cos \alpha$ azimuthal response resulting in unlike signs at zero and 180 degrees. This difference in signs allows the strain to be summed with the inertial to provide maximum cancellation of fundamental mode Rayleigh waves from one direction and maximum addition from the opposite direction. Since the microseisms used in the composite were arriving from the east, the west directional array component was selected as it provides maximum cancellation of signal from the east.

The block diagram in figure 8 shows how the data were processed. The event as recorded by the east strain seismograph was summed with the strain record of the microseismic storm prior to the final summation. Similarly, the event as recorded by the east inertial seismograph was summed with the inertial record of the microseisms prior to the final summation. The resulting composite is shown in figures 9 and 10. Trace 1 shows the signal used in the composite and represents the summation of the signals from the east strain and inertial seismograph outputs. Trace 4 is background noise as recorded originally by the east inertial seismograph. Trace 3 is the same background noise sample with the event superimposed as recorded by the east inertial. Trace 2 is the west component of the directional array.

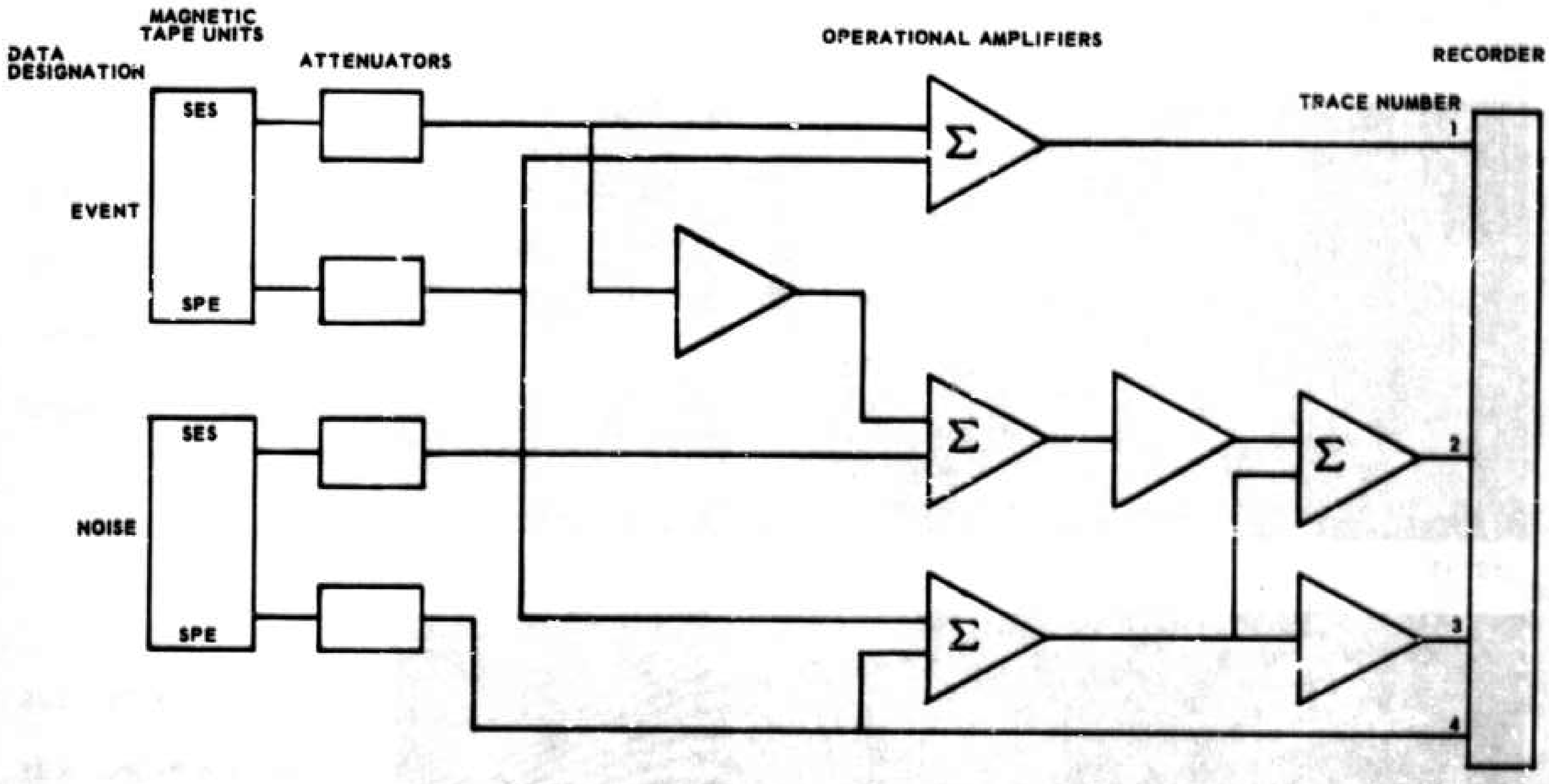
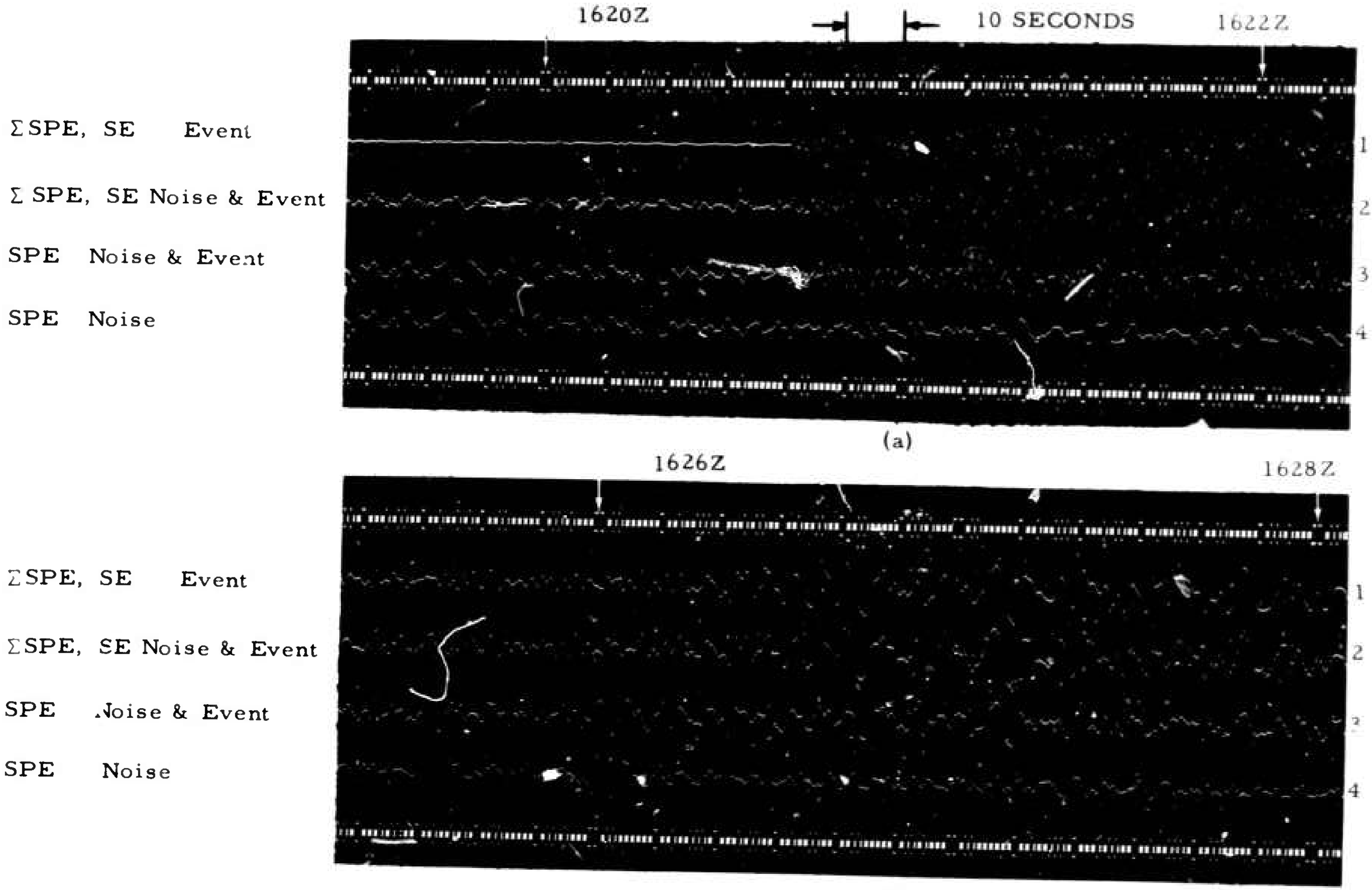


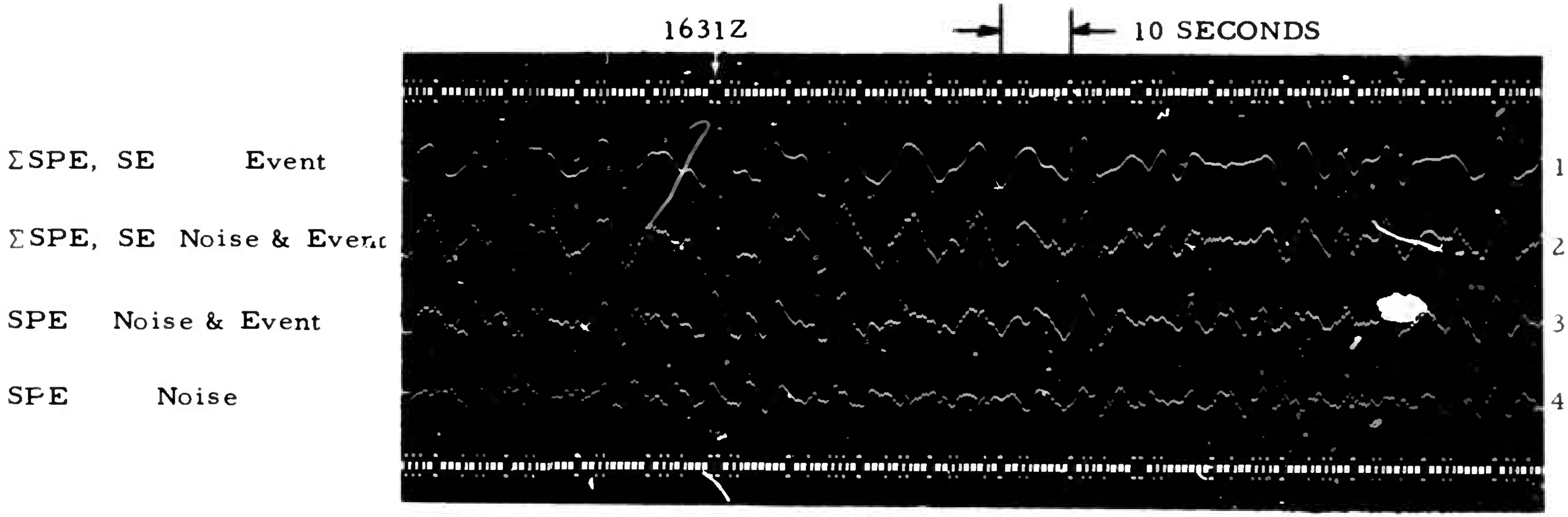
Figure 8. Block diagram showing process used to make the composite of the seismic event and noise data used to illustrate the effectiveness of the strain directional array for enhancement of surface waves. The east strain (SES) and east inertial (SPE) seismograph data were used

G 2133

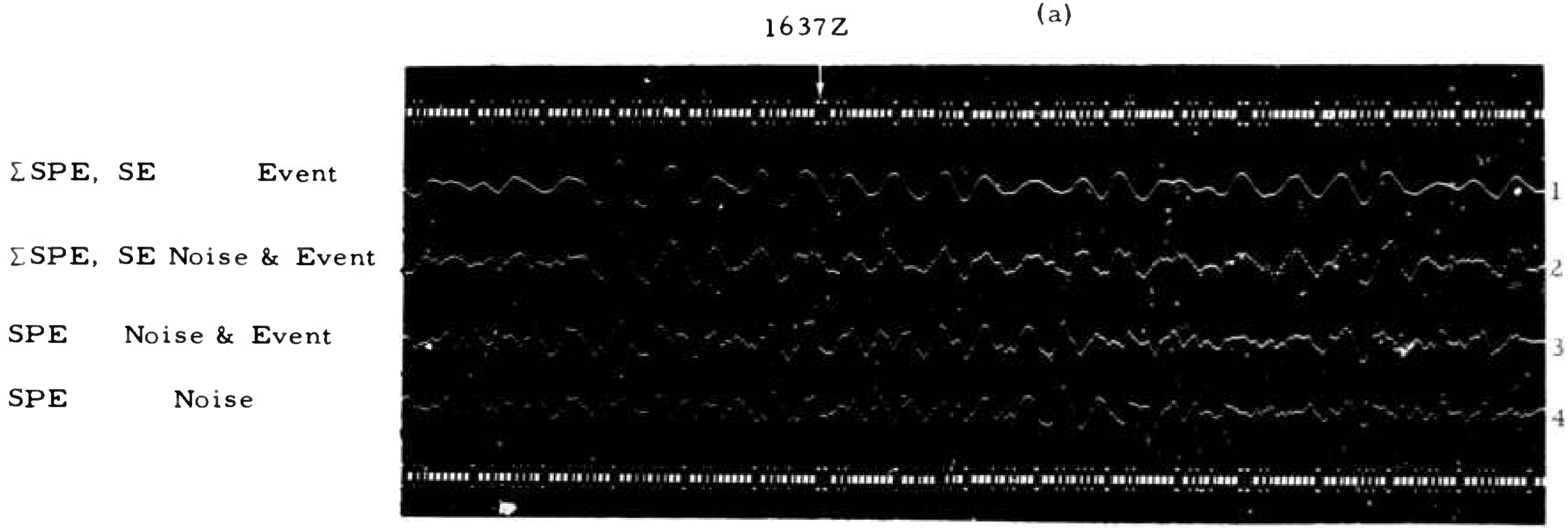


(b)

Figure 9. Seismograms illustrating the effectiveness of the west strain directional array (trace 2) in reducing the storm microseisms (beginning of trace 2, figure a) as recorded by east inertial (trace 4) and enhancing the detection of the horizontal component of body waves (figure 9a) and surface waves (figure 9b) from a teleseismic event (trace 1)



(a)



(b)

Figure 10. Seismograms illustrating the effectiveness of the west strain directional array (trace 2) in reducing the storm microseisms as recorded by the east inertial (trace 4) and enhancing the horizontal component of surface waves (figure 10a and 10b) from a teleseismic event (trace 1)

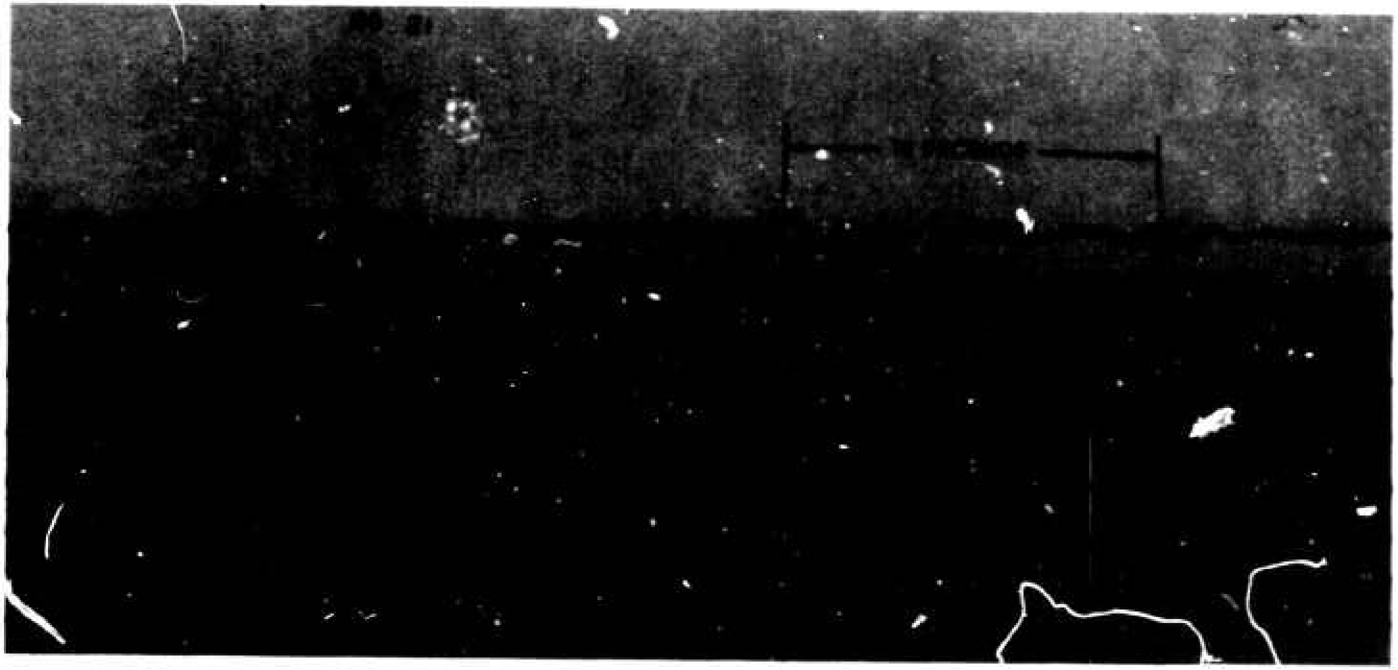
Figure 8a shows how effective the directional array is in reducing the level of the 5- to 6-second microseisms (see traces 2 and 3 for the first 80 seconds). The microseisms were reduced by at least 6 dB/octave. Therefore, fundamental Rayleigh waves arriving from the west will have an S/N improvement of at least 12 dB/octave. Figure 9a shows the initial arrival of the event and a comparison of trace 2 with 1 shows how the array was able to restore the event in contrast with the signal detected by the east inertial alone. In figure 9b, the initial arrival of the surface group can be easily detected on the west array component, but cannot be detected on the east inertial trace 3. Comparing traces 3 and 4 in figures 10a and 10b reveals contamination of the surface waves by the microseisms to a point where background noise and signal cannot be separated. However, the west strain array component, trace 2, is still able to restore the surface waves with little or no contamination.

5.4 WAVE IDENTIFICATION

Horizontally polarized transverse waves will be recorded, dependent on azimuth, by horizontal strain and inertial seismographs. The waves will not, however, be recorded by either the vertical strain or inertial seismographs. Figure 11 is the recording by strain and inertial seismographs of the SKS phase of an earthquake whose epicenter was approximately 96° from WMSO. The vertical strain seismograms are observed to have appreciable amplitudes. They indicate the presence of the vertical component of transverse waves, SV. The following discusses the results of theoretical considerations given the displacement and differential displacement due to incident SV waves. Since the amplitude responses of the strain and inertial seismographs at WMSO have been equalized to compensate for the 6 dB per octave increase of differential displacement with increasing frequency, where the displacement is constant, only the relationship of differential displacement to displacement at one frequency need be considered.

Expressions for displacement due to incident SV waves have been derived by Huang (1966) who allowed for variations of parameters, for example, angle of incidence, frequency, Poisson's ratio, shear wave velocity, normal stress along the surface, and depth. Employing Huang's expressions, relative amplitudes of vertical and horizontal surface displacement, horizontal differential displacement at the surface, and vertical differential displacement between 18 and 36 meters below the surface were obtained and are presented in figure 12 as a function of the angle of incidence. The values of differential displacement have been multiplied by 50 for improved resolution. Poisson's ratio was assigned a value of 0.3 and the normal stress along the surface assumed to be zero.

SPN	107K
SN	8400K
Σ SN, SE	6750K
SE	5400K
SPE	112K
SPN	105K
SPZ	107K
SZ_1	18900K
SZ_2	18700K



SPN – SHORT PERIOD NORTH INERTIAL
SN – SHORT PERIOD NORTH STRAIN
Σ SN, SE – SUMMATION SHORT PERIOD NORTH AND EAST STRAINS
SE – SHORT PERIOD EAST STRAIN
SPE – SHORT PERIOD EAST INERTIAL
SPZ – SHORT PERIOD VERTICAL INERTIAL
SZ_1 – SHORT PERIOD VERTICAL STRAIN IN STEEL-CASED BOREHOLE
SZ_2 – SHORT PERIOD VERTICAL STRAIN IN PLASTIC-CASED BOREHOLE

WMSO
RECORD NO. 335
01 DEC 1966

Figure 11. Seismogram illustrating the response of strain and inertial seismographs to the SV component of the phase SKS

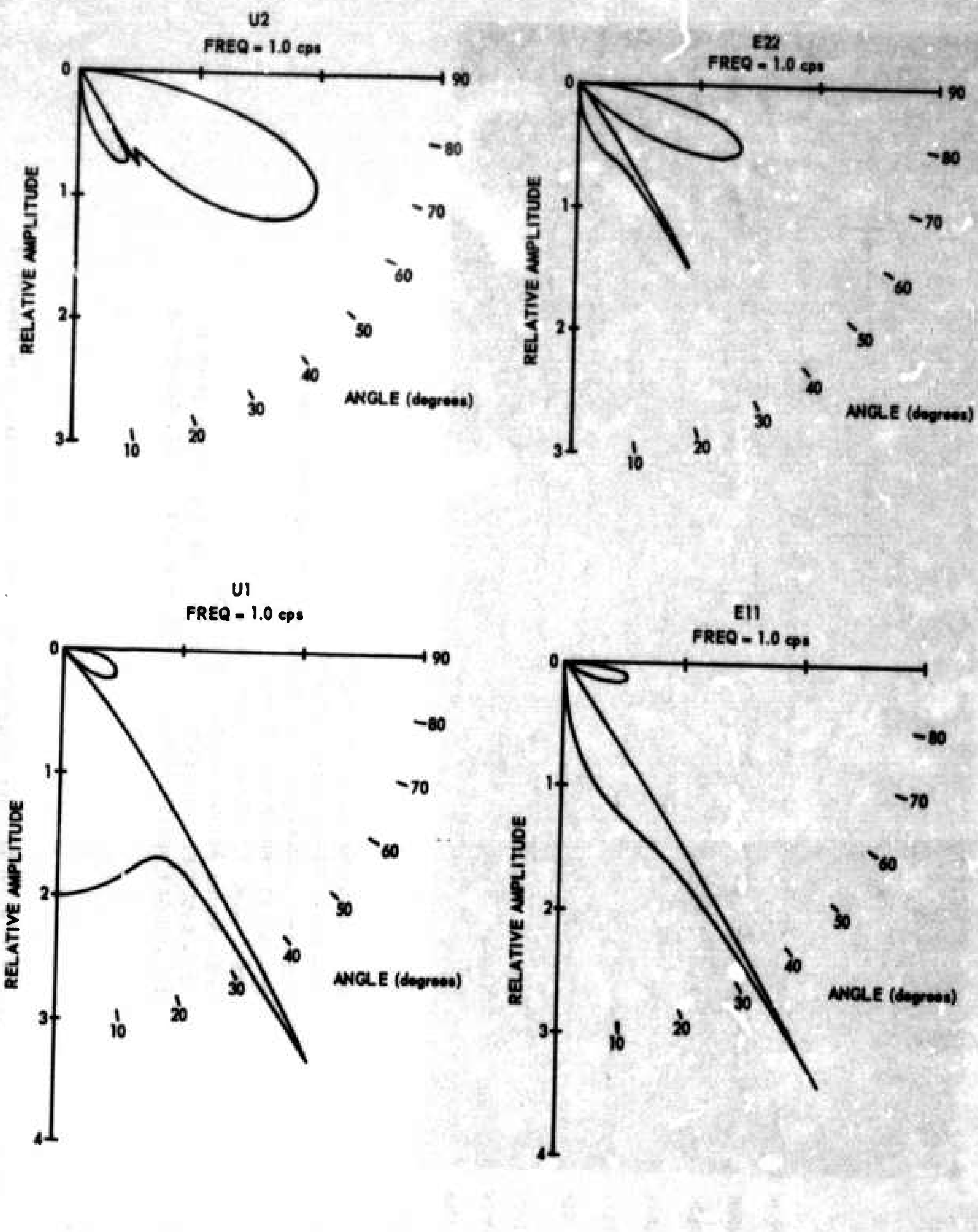


Figure 12. Polar plots of the relative vertical displacement U2, horizontal displacement U1, vertical differential displacement E22, horizontal differential displacement E11 due to incident SV waves plotted as a function of the angle of incidence. The values of differential displacement, E22 and E11, have been multiplied by 50 for improved resolution

G 2134

For simplicity, it will be assumed that both a horizontal strain and inertial seismometer are oriented in the direction of propagation of the incident waves, hence removing azimuthal responses from consideration.

From figure 12, the horizontal displacement is seen essentially unchanged in magnitude from 0° to 30° incidence corresponding to teleseismic earthquakes whose epicentral distances are approximately 30° or greater. The vertical inertial seismograph if operating at the same magnification as the horizontal inertial seismograph will record only from about 1/2 to zero the trace amplitude of the horizontal for these same epicentral distances. Therefore, teleseismic body phases arriving as transverse waves will be recorded with relatively large amplitudes by the horizontal inertial seismograph (including both SH and SV components) whereas the vertical inertial seismograph will record little or none of the disturbances. This is observed on seismograms.

From an incidence of 30°, the vertical and horizontal differential displacements due to SV, like the vertical displacement, approach zero as the angle of incidence approaches zero. If the magnification of the strain seismographs, however, are adjusted to produce trace amplitudes equal to those of a vertical inertial seismogram for fundamental Rayleigh, the strain seismograms will have larger amplitudes than the vertical inertial for SV waves arriving from epicentral distances beyond 26°. The vertical strain seismogram will have larger amplitudes for all epicentral distances except where its response is zero.

The vertical strain seismograph, since it does not record SH, will therefore probably be the most useful seismograph for detecting and identifying the SV component of incident transverse waves when both SH and SV are present. (The magnification of the vertical and horizontal strain seismographs at 1.0 would be about 133 and 44 times that of the vertical inertial, respectively, to have equal trace amplitudes for fundamental Rayleigh.)

SV incident near the critical angle, where the reflected longitudinal wave would be horizontal, will be recorded with large amplitudes by the strain and horizontal inertial seismographs. This angle is 32.31° for $\sigma = 0.3$ corresponding to an epicentral distance of about 26°.

It is important to note that the vertical and horizontal differential displacements do not maintain a constant proportionality for all angles of incidence (see figure 12), nor does the horizontal differential displacement ever exceed the vertical by more than a factor of 2.4.

The data used in figure 12 were computed where the expression including the normal stress along the surface was assigned a value of zero. This may be an accurate value in weathered surface material; however, the vertical differential displacement is measured between points approximately 18 and 36 meters below the surface where the rock has been subjected to less weathering. By using a value greater than zero even wider difference in vertical and horizontal differential displacement is observed, where the value zero is still maintained for the horizontal case. Close examination of empirical data will be necessary to arrive at the value most suitable for WMSO.

6. REFERENCES

Huang, Y. T., 1966, Effect of an elastically restrained boundary on SV-wave radiation patterns: Teledyne Industries, Geotech Division, Technical Report No. 66-111

APPENDIX TO TECHNICAL REPORT NO. 67-2

STATEMENT OF WORK TO BE DONE
AFTAC PROJECT AUTHORIZATION NO. VELA T/5081

EXHIBIT "A"

STATEMENT OF WORK TO BE DONE

AFTAC Project Authorization No. VELA T/5081

1. Instrumentation Development

a. Complete the development of the variable-capacitance transducer to extend the strain seismograph response to longer periods.

b. Complete the modification and testing of the seismometer transducers, amplifiers, filters, and associated circuitry to insure a consistent phase relationship between pendulum and strain seismographs.

c. Design and install secular strain monitors to improve the horizontal strain seismograph operation.

d. Improve the stability of the seismograph circuitry by installing a separate phototube amplifier shelter.

2. Seismograph Development

a. Vertical Strain Seismograph

(1) Complete this design of the vertical strain seismograph by improving the anchor design, reshaping the instrument sections, and improving the mechanical reliability relative to installation, position locking, and removal.

(2) Improve the operation of the vertical strain seismograph by incorporating the developments listed in paragraphs 1a, 1b, and 2a(1).

b. Horizontal Strain Seismographs

(1) Improve the design of the horizontal strain seismographs by the addition of secular strain controls and seismograph housing modifications.

(2) Improve the operation of the horizontal strain seismographs by incorporating the developments listed in paragraphs 1a, 1b, 1c, 1d, and 2b(1).

3. Evaluation

a. Vertical Strain Seismograph. Test and evaluate the operation of the improved vertical strain seismograph in a new uncased borehole to be located adjacent to the present cased borehole. The uncased borehole is to be oil-filled and may contain the following features:

(1) Steel casing sections may be used for instrument anchor locations if the sections are decoupled from each other so that longitudinal casing rigidity is less than that of the surrounding rock formation.

(2) A continuous plastic casing may be used to maintain wall smoothness and hole integrity provided that the plastic is more compliant than the surrounding rock formation.

(3) Combinations of (1) and (2) may be used. In all instances where instrument achors must lock against a borehole liner, the liner must be rigidly bonded to the borehole wall.

To facilitate the positioning of the instrument in the borehole, a permanent anchor may be used in the cased and uncased holes. This fixed depth operation might help to avoid the anchor malfunctioning which has been experienced.

b. Horizontal Strain Seismographs. Test and evaluate the operation of the improved horizontal strain seismographs in their improved housing.

4. Applications

a. Record seismic data at Wichita Mountains Seismological Observatory on magnetic tape and 16 mm film; process magnetic tape data at the Geotechnical Corporation's central data processing facility and elsewhere as required; and determine spectra, phase, and coherency among the vertical strain, horizontal strain, and several pendulum seismometer control signals.

b. Experimentally corroborate the vertical strain seismograph performance relative to the 2 crossed-horizontal strain seismographs to verify that true earth strains are faithfully recorded by the vertical strain instrument.

c. Develop a thorough understanding and evaluation of the phase and amplitude performance of the strain seismographs and related pendulum systems.

d. Determine the usefulness of strain seismographs when used singularly and in combination with inertial instruments for wave identification, signal enhancement, detection of long-period signals, and rejection of noise arriving from selected azimuths. Determine the usefulness of strain seismographs in distinguishing between earthquakes and explosions. Schedule the program so as to provide preliminary results on the P-wave enhancement portion of the program not later than 30 Sept 65.

*5. Drawings. Provide drawings and specifications on items specified in paragraphs 2a(1), 2a(2), 2b(1), 2b(2), and the uncased borehole as outlined in paragraph 3 according to Data Items E-23-11.0, E-2-11.0, E-4-11.0, E-5-11.0, E-7-11.0, and T-13-28.0 contained in AFSCM 310-1. These drawings shall conform to the instructions contained in Attachment 2. Wherever Data Items conflict with Attachment 2, the latter will take precedence. Reproduction shall be accomplished in accordance with Data Item E-4-11.0, paragraphs 1b, 1f, 7, 9, 10, 11, and 12c(3), microfilm on aperture cards and nonreproducible paper copies. Index card keypunch format may vary from specifications as approved by AFTAC through the project officer. Aperture cards should be furnished in 2 copies, 1 positive and 1 negative.

6. Reports. Provide monthly, quarterly, final, milestone, and special progress reports in accordance with Data Item S-17-12.0, first sentence of paragraph 1. Wherever the Data Item conflicts with Attachment 1, the latter will take precedence. All reports under this project will be forwarded to HQ USAF (AFTAC/VELA Seismological Center), Wash., D. C. 20333.

*For the purposes of this contract, the provisions of paragraph 5 of this Exhibit "A" are hereby waived. In lieu thereof, the following provisions shall apply:

"5. Drawings. Drawings shall be furnished in accordance with the provisions of line item 7 of the DD Form 1423 and attachments thereto."

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Teledyne Industries Geotech Division 3401 Shiloh Road, Garland, Texas 75040	2a. REPORT SECURITY CLASSIFICATION 2b. GROUP

3. REPORT TITLE

Quarterly Report No. 6, Project VT/5081
Multicomponent Strain Seismograph

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Quarterly Report, 1 October-31 December 1966

5. AUTHOR(S) (Last name, first name, initial)

Girard, B. W., Kirklin, R. H., Sherwin, J. R., and Shopland, R. C.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
20 January 1967	32	One

8a. CONTRACT OR GRANT NO. AF 33(657)-15288 b. PROJECT NO. VELA T/5081 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 67-2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

Qualified requestors may obtain copies of this report from DDC

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY HQ USAF (AFTAC/VELA Seismological Center) Washington, D. C. 20333

13. ABSTRACT

Phase responses of the strain seismographs indicate appreciable deviations from theory. However, good cancellation of Rayleigh waves with combinations of strain and inertial seismographs indicates acceptable phase match. Unpredicted phase discrepancies of approximately 5 degrees in the 0.8 cps galvanometers of the strain seismographs can be eliminated by a simple conversion to a 3 cps system. Uncertainties in the phase response of the calibrators on the strain seismometers can be resolved by installing a monitor at the calibrator.

The main effort on the program has been shifted toward evaluating the directional capabilities of the strain-inertial combinations in the long-period spectrum. A combination of long-period strain and inertial seismographs with matched frequency responses has been designed and is being put into operation at WMSO. The technique of detecting long-period (15-20 sec) surface waves masked either by microseisms or by surface waves from another event is demonstrated using 6 sec surface waves from the short-period strain directional array.

To minimize off-line summing of data from individual seismographs of the eight-component short-period strain directional array, the data will be summed on-line and recorded on a Develocorder at WMSO. This system will be an operational prototype of a strain system capable of enhancing short-period signals. The transition to on-line operation is nearly complete.

A comparison of the plastic-cased borehole and the steel-cased borehole indicates that the latter is not responding properly to earth strain.

Theoretical expressions for displacement and differential displacement due to incident SV waves have been derived. Relative values of displacement and differential displacement have been computed and are compared to a recording by the strain and inertial seismographs at WMSO.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification